EXPERIMENTAL INVESTIGATION AND MODELLING MICRODRILLING OPERATION OF AEROSPACE MATERIAL

A thesis submitted in partial fulfillment of the requirement for the degrees of

Bachelor of Technology

In

Mechanical Engineering

By

DILIP KUMAR BAGAL

ROLL NO: 108ME025

DEPARTMENT OF MECHANICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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UNDER THE SUPERVISION

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Prof. K. P. MAITY

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NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA-769008(INDIA)

Certificate

This is to certify that the thesis entitled " ***experimental investigation and modeling micro-drilling operation of aerospace material***" submitted by Dilip Kumar Bagal (108ME025) in fulfillment of the requirement for the award of Bachelor of Technology Degree in Mechanical Engineering at the National Institute of Technology, Rourkela (Deemed University) is a genuine work carried out under my supervision.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Prof. K. P. Maity
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Rourkela- 769008

DATE :
PLACE :

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CONTENTS: *Page no.*

ABSTRACT:

In the present growing world of technology, the micro-machining process has demanding operation in various sectors like aerospace, oil, defense, automobile, biomedical science and many industries at micro and nano levels of manufacturing and designing. In various types of micro machining, micro-drilling is the part of solid tool based micro-machining operation. Generally micro-drilling is used to fabricate micro-holes in micro-products. In the present investigation convectional micro-drilling has been carried out in Aerospace material i.e. P.M.M.A.(Poly Methyl Meth-Acrylate). Here an endeavor has been made for finding the optimal conditions to the micro-drilling operation upon acrylic sheet of polymer. For the optimum condition for micro-drilling operation, various factors are to be considered and these factors are known as process control parameters. In this study, the cutting speed and feed rate will be taken as process parameters, and circularity error, drilling torque, thrust force and machining time has been measured. Finite Element Modeling will be carried out by using ABACUS software.

List of figures:

List of Tables:

INTRODUCTION:

Micro-drilling processes have been widely used to produce micro holes such as micro dies and molds, fuel injection nozzles, watches, bearings and printed circuit boards etc. And it has more attention in a wide spectrum of precision production industries. Experiments are conducted to investigate the effectiveness of drilling processes by measuring the hole quality after micro-machining. Two aspects, location error and oversize of the hole, of drilling quality are measured. Depending on the type of drills and drilling processes, it may occur that the drill walks on the surface of the work piece before entering the part. Whirling of the drill edge at the time of penetration into the work piece degrades hole quality as well. In order to measure circularity error, We requires the measurement systems such as optical microscope, and to measure drilling torque and thrust force, it is to be use of Dynamometer of Kistler (9272A). The way to optimize the DOE it is required orthogonal array . The orthogonal array of L_9 is used in this experiment. The number of levels is taken as 3 for the orthogonal array. Here the work material is taken as PMMA which has characteristics of transparent thermoplastic and hence often used as a lightweight or shatter-resistant alternative to glass. Sometimes it is known as an acrylic glass. The sheet of 5mm in thickness, 85 mm in length and 50mm in width is to be considered in the experiment. The machine used in this experiment is Computer Numeric Control (CNC) system with carbide drill bit of 1mm diameter and having point angle 118° and 23mm flank length. Generally in micro-drilling procedure the contour of hole is not perfect due to the error in the circular diameter in the material sheet, and this error is known as local circularity error. It mainly affects the whole dimension of the product. So, the efficiency of the model is reduced in many cases.

CHAPTER-1 DRILLING PROCESS:

Drilling is the process of generating circular hole in the work-piece by using a rotating cutting tool known as drill bit. Bits are attached in a tool called a drill which helps to rotate drill-bit and also gives torque and axial force to generate the cylindrical hole in work-piece material [21].

Types of drills:

According to

1.1 Material:

1.1.1 *Steels*

Generally steels are used to manufacture of drill-bit in a large number.

- Low carbon steel: Mainly used for wood material as work-piece. The market value of this type of material tool is less expensive than other type of material tool is less expensive than other type of longer-lived bits.
- High carbon steel (HCS): These are more hardening and tempering an nature as compared to low carbon steel.
- High speed steel: This type of material is highly resistive towards heat and largely used in commercial applications.
- Cobalt steel alloy: In this type of alloy the percentage of cobalt is more in high speed steel.
- High-moly tool steel: Its heat treating temperature is at 1196° C i.e 2185° F and also has nitro-carburize finished at 510° C i.e. 950° F which stands for higher drilling temperature.

1.1.2 *Other type of drill bit*

- Tungsten carbide: These are extremely hard materials which can drill virtually all materials. Because of their brittleness and high cost they are usually manufactured for drill-bit tip.

- Polycrystalline diamond: This type of drill-bit is highly wear resistive and hardest in nature from all tool material. A layer of diamond granules of thickness 0.5 mm (0.019") attached as a sintered mass to above tungsten carbide.

1.1.3 *Coatings*

- Black oxide: This type of coating gives heat resistance, lubricity and corrosion resistance which results longer life for drill-bit than uncoated high speed steel drill-bit.
- Titanium nitride (TiN): This is a type of hard ceramic material which expands the cutting tool life by three or more times by coating on HSS drill-bit.
- Titanium aluminum nitride (TiAlN): Its extended tool life is five or more times than TiN coated drill-bit.
- Titanium carbon nitride (TiCN): This material is superior as compared to Titanium Nitride.
- Diamond powder: The diamond powder coated drill bits are mostly used for cutting tile, stone and other hard materials.
- Zirconium nitride: This type of coated drill bit usually applied in few craftsman tools.

1.2 Size:

As per the contour of diameter, drill-bit are characterized into three types such as

(a) Micro (25-500mm),

(b) Moderate (3-25mm) and

(c) Large (25-40mm)

1.3 Number of flutes:

Based on the no. of flutes in drill-bit, they are named as follows

(a) Two-most common drill,

(b) Single-gun drill and

(c) Three/four slot drill

1.4 Helix angle:

According to the measurement of helix angle, the drill bits are subdivided into four types such as

(a) Usual-20-35 degree drill,

(b) Large-45-60 degree drill,

(c) Zero degree spade drill and

(d) Micro-drill

1.5 Universal Drill Bit:

These drill bits are widely used in metals, plastics, woods and most other materials. These are of four types like

(a) Twist drill bit: Now-a-days these types of drill bit are manufactured in a huge amount. Its is ranging from 0.051 to 89 mm (0.002 to 3.5 inch) and length up to 650 mm (25.5 inch).

(b) Step drill bit: The tip of this type of drill bit ground down to different diameters. The ground diameter and original diameter have same flute characteristics which help to keep the bit from clogging operation while drilling is processed upon softer materials.

(c) Unibit: This is a conical shaped drill bit having a stair-step profile. These are usually worked on softer sheet metals and other materials like plywood, particle board, acrylic sheets, laminate sheets and drywall.

(d) Hole saw: The hole saw is a type of hole cutter having annular shaped saw blade with pilot drill bit at the center.

1.6 Metal Drill Bit:

(a) Center and Spotting drill bits:

Center type:-The center drill bits are used to generate conical holes in the end of a work-piece for lathe center.

Spotting type:-As the center drill bits are technically incorrect in practice and should not fit for production uses, the spotting drill bit with countersinks are used as to ignore premature failure and certain loss in hole quality.

(b) Core drill bits: This is used to expand the previously existing hole left by foundry core.

(c) Countersink drill bits: The countersink drill-bit is used to cut of conical hole in a manufacturing object.

(d) Ejector drill bits: This type of drill bit helps in drilling of medium to large diameter holes i.e. from ¾ to 4 inch diameter. The drill bit body comprises of a tube inside a tube.

(e) Gun drill bits: These are straight fluted drills in which the cutting fluid injects through hollow body of drill-bit.

(f) Index-able drill bit: These are normally used in CNC machines and other production equipments. Drill bits are no longer in deep than 5 times of its diameter.

(g) Left-hand drill-bit: This type of drill bit is similar to twist drill bit and the common example of it is screw extractor.

(h) Metal spade bit: The inserts of this type of drill bit are of size ranging from 11 to 3 mm.

(i) Trepan: Trepans are otherwise known as BTA drill bits, and its bit diameter ranges from 6 to 14 inches and of hole depth from 12 inch to 71 feet.

1.7 L/D Ratio: As per the ratio of length to diameter of drill bit the drill bits are again classified as follows

(a) general-5-10,

(b) small-center drill and

(c) large-deep hole drill

1.8 Shank type: Drills are categorized into two types according to shape of shank and given below as

(a) Straight type and

(b) Tapered

CHAPTER-2 BRIEF ABOUT PMMA:

Mainly PMMA is a polymer of amorphous thermoplastic material. Its IUPAC name is Poly methyl 2-methylpropenoate.The structure of monomer i.e. methyl meth-acrylate is given by

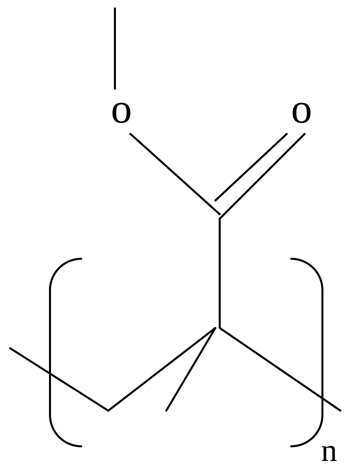

Figure No.1: Structure of monomer in PMMA[21]

2.1 PROPERTIES:

1) Its molecular formula is $(C_5 O_2 H_8)_n$.

2) The glass transition temperature of purest form of PMMA material is nearly 115°C.

3) For injection moulding PMMA is processed at temperetaure from 210°C to 250°C and for extrusion process corresponding temperature is from 160°C to 200°C.

4) The melting point of PMMA is of 160°C (320°F) and boiling point is 200°C (392°F).

5) Refractive index of PMMA is 1.4914 at wavelength of 587.6 nm.

6) It is very high weathering resistance, high value of optical transparency and clarity retention with or without colourants.

7) It has low water absorption capacity and good impact resistance.

8) Polymer has good resistive capacity to weak acids and alkalis.

9) This can be solvent cemented.

10) Its shrinkage value is low i.e. from 0.4 % to 0.7%.

11) For improvement of impact strength, butyl acrylate is mixed.

12) For protection or filtration of UV light, dyes are added to some extent in polymer.

13) For improvement of cost-effectiveness, fillers should be added.

14) Its maximum limit of water absorption ratio is in the range of 0.3–0.4% by weight.

15) Its coefficient of thermal expansion is relatively high at $(5–10) \times 10^{-5}$ /K.

2.2 ENGINEERING APPLICATIONS:

PMMA is used in various areas of engineering such as precision drawing and writing instruments, vehicle rear lights, warning triangles, lacquers, glazing units, sheeting, reflectors and signs, lamp cases, lenses, medical equipments, business machines, LCD backlit display panels etc.

2.3 COMMODITY APPLICATIONS:

For raw materials used such as light-emitting diode casings, spectacles, Shop-fittings, signs, point-of-sale display and racks etc.

CHAPTER-3 LITRETURE SURVEY:

Many dedicated researchers have done their research projects on micro machining processes from various part of the world. The survey consists of some of the journal papers by them which are discussed below

Ahilan et al [1] investigated upon turning process by taking cutting speed, feed rate, depth of cut and nose radius as process parameters, and outputs are surface roughness and power consumption optimized by Grey Based Taguchi method. His experiments are based upon AISI304 stainless steel by taking Taguchi's L_{27} orthogonal array in design of experiment. He found that cutting speed of 100m/min, feed rate of 0.1mm/rev, depth of cut of 0.2mm and nose radius of 0.4mm are the optimal conditions to decrease surface roughness from 1.74µm to 1.14µm and power consumption from 320watts to 245watts. Again he added that cutting speed influences 35.47%, followed by feed rate 26.12%, depth of cut 18.16% and nose radius by 10.63%.

Shih-Hsing et al [2] investigated on optimization of injection molding process in glass fiber reinforced polycarbonate composites as work piece by using grey relational analysis. The experiment is examined by CAE software package for forecasting the shear layer thickness and L_9 Orthogonal array is taken with 4 process parameters i.e. filling time, melt temperature, die temperature and ram speed in 3 levels. He found that the quality of product was improved by 20% which is dramatically increased productivity by improvement of quality of part, reducing rejects by cycle time, inspection time, cost and scrap and gave better scheduling in product.

Fung Chin-Ping [3] reported on wear property of fiber-reinforced poly-butylene terephthalate in the injection molding process by nine experimental runs with $L_9(3^4)$ orthogonal array by taking filling time, melt temperature, mold temperature and ram speed with 3 levels. He reported that volume losses by parallel and perpendicular sliding directions are optimized at 2sec of filling time, 260°C of melting temperature, 90°C of molding temperature and 100% of ram speed.

Chen Ming-Fei et al [4] reported upon the optimization of direct CO_2 laser cutting process in PMMA of 6mm thickness by using grey relational analysis. They have taken 3 levels of 4 process parameters like assisted gas flow rate, laser repetition frequency, cutting speed and laser defocused position, and their responses are surface roughness and optical transmittance ratio. They concluded that the assisted-gas flow rate and beam focus depth have largest effects on the quality of cut surface for direct laser cutting process, and the optimum parameters are 20NL/min of gas flow rate, 5 kHz of laser pulse repetition frequency, 2mm/s of cutting speed and position of focus on material is Zero.

Tsai Ming-Jong and Li Chen-Hao [5] discussed upon the optimization of laser cutting process of a Quad Flat Non-lead (QFN) strip by using six performance characteristics. They gave the optimal condition by analyzing by grey based relational grade that at current of 29A, frequency of 2 kHz, and cutting speed of 2mm/s are the significant parameters in the experiment. They concluded that with lowest grade results the process parameters decrease as the width of heat affected zone and cutting line increase.

Li Chun-Hao and Tsai [6] reported upon the optimization of laser cutting process for 2 flash modules with special using grey relational analysis by taking process parameters as laser average power, laser cutting speed, laser beam focusing spot size and Q-switch frequency. They were optimizing the outputs of width and surface roughness of heat affected zone. They have concluded that the optimal condition of 15 W of average laser power, 200 mm/s of laser cutting speed, 4μm of laser beam focusing spot size and 100 kHz of Q-switch frequency, gave the output of surface roughness of 3.76μm and for the width of heat affected zone of 25μm for both the samples.

P. S. Kao and H. Hocheng [7] both are investigated upon optimization of Electro-chemical polishing process of 316L stainless steel by taking process parameters of temperature, current density and electrolyte composition, and the output responses of surface roughness and passive strength ratio by the application of grey based relational Taguchi method. Their conducted confirmation test results that the surface roughness ratio reduced from 50% to 4.75% and the passive strength ratio increased from 95 % to 100%.

Senthil Kumar Velusamy and Uday Omprakash Bidwai [8] have been experimented on the effectiveness of current, pulse on-time, flushing pressures which are input in the electrical discharge machining process. In the hand the outputs are metal removal rate, tool wear rate of sintered aluminum alloy with 5% and 2.5% of TiC reinforcement. They found that increase in flushing pressure increased EWR in case of second reinforcement. But, the 1st reinforcement is different due to the formation of bigger size of craters TWR is slightly decreased.

P Matoorian et al [9] have investigated on the optimization method in electrical discharge turning process on the orthogonal array of L_{18} orthogonal array in which design of experiment has been done. They are taken process parameters as intensity, time in pulse-on and pulse-off, voltage, servo and rotational speed.

J Kopac and P Krajnik [10] both have discussed about optimization process of flank milling 3 level parameters as coolant application, no of flute, cutting speed, feed per tooth, axial depth and radial depth. They optimize this experiment by grey relational analysis using L_{18} orthogonal array of design. They concluded that reducing feed rate improves the performance and the tool life.

M M Okasha and P T Mativenga [11] tested upon sequential laser mechanical drilling process on aerospace material of inconel 718 alloy. The performance of the twist drill improved by this operation and also helps in reducing burr size and increasing of tool life. They introduced Laser-Pilot-Mech technique for minimization of thrust force and torque value.

Tsai Chih-Hung et al [12] created a vendor evaluation factors model on characteristics of demand of raw materials of an enterprise by using grey theory. In this optimization method they concluded that the ranking order changes with the different value of weighs in each evaluation factor.

Goutam Nandi et al [13] modeled a optimal environment in submerged arc welding process by taking four input process parameters with five levels and they applied two hybrid method of Taguchi to optimize four bead geometrical parameters by taking L_{25} orthogonal array matrix design.

CHAPTER-4 EXPERIMENTAL LAYOUT:

4.1 EXPERIMENTAL SET UP:

In the present investigation, 5mm thicker PMMA sheet was taken into account as a work-piece, having length of 80 mm and breadth of 50 mm. The drill-bit which is applied in this experiment is solid carbide drill-bit which is a type of straight shank twisted drill. The standard diameter of this type of drill-bit is 1mm. The point angle and flute length are 118° and 23 mm respectively. The whole operation of micro-drilling is carried out in the central workshop of NIT Rourkela, India. The output parameter of torque and thrust force was measured by the arrangement of 9272A type Kistler Co. prepared quartz 4 component dynamometer and 5070A type multi-channeled charge amplifier. And the local circularity error and time are measured by means of JEOL SEM-6480LV machine and stop watch respectively.

4.2 DRILL BIT SPECIFICATION:

Type--------------------- Solid carbide drill

Diameter---------------- 1mm

Flute length------------- 23mm

Point angle-------------- 118°

4.3 WORK-PIECE SPECIFICATION:

Type---------------------- PMMA (AEROSPACE MATERIAL)

Melting point------------ 160°C (433K)

Boiling point------------- 200°C (473K)

Refractive index--------- 1.4914

4.4 AMPLIFIER SPECIFICATION:

Type----------------------- 5070A

Company ----------------- Kistler Coporation

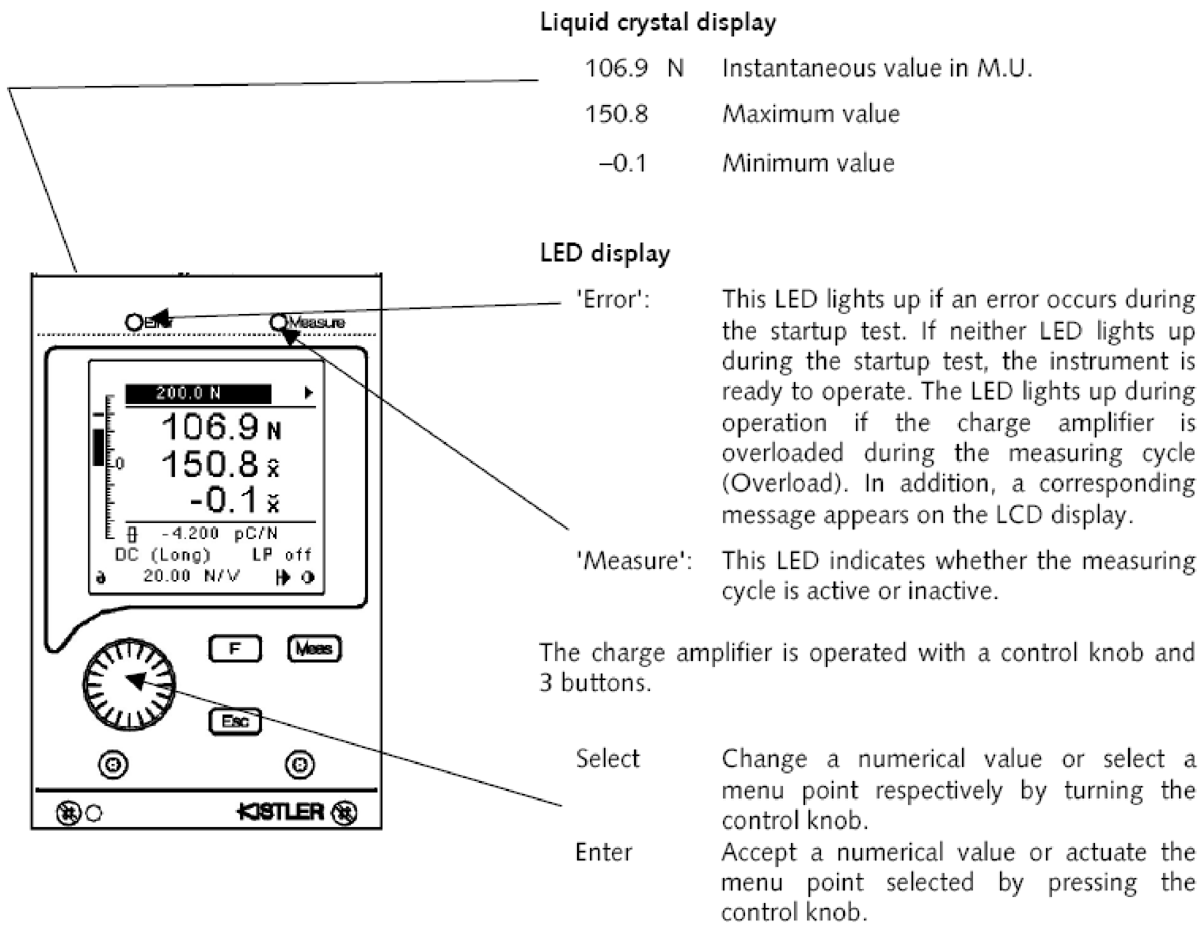

Figure No. 2: Display of charged amplifier

4.5 LATHE DYNAMOMETER:

While machining on lathe, the excess metal is removed in the form of chips and the work-piece (w/p) is given proper shape. During machining, tool and the w/p material experience intense forces and temperature at the chip formation zone. The nature and magnitude cutting forces depends on the complex phenomena of metal deformation involving tool and work-piece material characteristics, tool geometry, internal and external friction at interface and several other physical and chemical factors. Estimation of cutting forces is essential for determination of the power requirement of machine tools, design of machine tools and development of new cutting tool materials.

The forces experienced by a tool while drilling operation. The cutting force is represented as F_c (F_z), the feed force as F_s (F_x) and the thrust force as F_t (F_y). The tool is mounted on piezo-electric dynamometer which is mounted on the saddle of the lathe. The various cutting forces are picked by the charged amplifier which in turn digitize and display these forces. The specifications dynamometer is given below.

Figure No. 3: Tool dynamometer

Type-------------------- 9272A

Company--------------- Kistler Corporation

Table No. 1: SPECIFICATION OF LATHE DYNAMOMETER:-

Measuring range		
	Force/ moment	Range
	F_x	-5 – 5 kN
	F_y	-5 – 5 kN
	F_z	-5 – 20 kN
	M_z	-200 – 200 N-m
Natural frequency		
	f_n (x,y)	3.1 kHz
	f_n (z)	6.3 kHz
	f_n (Mz)	4.2 kHz
Temperature characteristics	Operation temperature	0 – 70 ^{o}C
	Temperature coefficient of sensitivity	-0.02 %/ ^{o}C
Weight		4.2 kg

4.6 SPECIFICATION OF DRILLER:

Type-------------------- Heavy duty drill (WDH type)

Company name------- Ralliwolf Limited, Bombay (400080)

Serial No------------- B913238

F/L amps------------- 2.55A

N/L RPM------------- 560 rpm

AC/DC volts---------- 235V

Figure No. 4: Experimental set up for Drill bit, Work-piece and Dynamometer

CHAPTER-5 PROCEDURE:

Firstly, the work-piece was cut according to above mentioned dimension i.e. 80*50*5 mm by cutter. Then two holes of 8mm and 12mm diameter are made by heavy duty driller to hold the work-piece tightly by the nuts and bolts. After drilled hole in work-piece, Kistler model 9272A piezoelectric drilling dynamometer is to be mounted on T-slot bed with T-type bolts. The above said PMMA strip is settled above the dynamometer by the help of two bolts and washers. With the aid of G-coding program in a CNC drilling machine, the spindle speed and feed are to be inserted as a input parameters in the micro-drilling operation. The output parameters of thrust force and torque are measured simultaneously which were displayed on monitor of amplifier monitor. The machining time is measured with the care of stop watch. After the micro-drilling process, the images of total 10 holes were to be measured by JEOL SEM machine at acceleration voltage of 15KV and magnification of X50.

5.1 EXPERIMENTAL DATA INSPECTION:

Design Of Experiment is based on the use of the orthogonal array for conducting small highly fractional experiments up to larger, full factorial experiments. The use of orthogonal arrays is just a methodology to design an experiment, But probably the most flexible an accommodating a variety of situations and yet easy for non-statistically oriented people to execute on a practical basis i.e. orthogonal array. Here we use L_9 with 3 levels means total no of experimental run is nine.

Table No. 2: VALUES OF INPUT PROCESS PARAMETERS:-

Process parameters	Code	LEVEL(1)	LEVEL(2)	LEVEL(3)
Feed rate(mm/min)	A	20	25	30
Spindle speed(RPM)	B	2000	2500	3000

5.2 STEPS FOR GREY RATIONAL ANALYSIS:

Following steps are to be considered for Grey Relational analysis:

STEP (i): Finding out the experimental data tables through DOE.

STEP (ii): Normalize the response parameters in the domain of < 0, 1 > by using following formula of lower the best

$$N_{ij} = \frac{(X_{ij})_{max} - X_{ij}}{(X_{ij})_{max} - (X_{ij})_{min}}$$

Where N_{ij}= Normalized value after grey relational generation

$(X_{ij})_{max}$= Maximum value of response parameter

$(X_{ij})_{min}$= Minimum value of response parameter and

X_{ij}= Value of response in i^{th} column and j^{th} raw of design matrix.

NOTE: Here i value varies from 1 to 4 and j value varies from 1 to 9.

STEP (iii): Calculate the grey relation co-efficient by using following formula

$$\gamma\,(x_{0j}, X_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}}$$

Where $\Delta_{ij} = |x_{0j} - X_{ij}|$ = Absolute value of the difference of x_{0j} and X_{ij}, and ξ= Distinguishing coefficient varies from 0 to 1.Here we are taking ξ as 0.5.

STEP (iv): After determining the grey relational coefficient, we have to take average value of grey coefficients and this average value is called Grey Relational Grade.

$$\Gamma = \frac{1}{n}\sum_{k=1}^{n} \gamma\,(x_i(k), x_j(k))$$ Where k= Number of tests.

STEP (v): Calculate total mean grey relational grade by using following formula

$$\Gamma_m = \frac{1}{n} \sum_{k=1}^{n} \Gamma(k)$$

STEP (vi): For determining S/N ratio for smaller the best, the following formula is used

$$\text{S/N ratio} = -10 \log \left[\frac{1}{n} \sum_{k=1}^{n} X_{ijk}^{2}\right]$$

STEP (vii): After determining S/N ratio, plot graphs by using Minitab software of version 14 then we can find the optimal settings for micro-drilling process parameters.

STEP (viii): Rank the predilection order as per the influence of input parameters in this optimization method.

5.3 FULL FACTORIAL DESIGN:-

Factors: 2 Replication No: 1

Base Runs: 9 Total Runs: 9

Base Blocks: 1 Total Blocks: 1

Number of levels: 3, 3

Table No. 3: DESIGN TABLE (RANDOMIZED):-

Run	Block	A	B	Feed rate	Spindle speed	Standard order
1	1	1	2	20	2500	2
2	1	1	1	20	2000	1
3	1	3	3	30	3000	9
4	1	1	3	20	3000	3
5	1	3	1	30	2000	7
6	1	2	2	25	2500	5
7	1	2	1	25	2000	4
8	1	3	2	30	2500	8
9	1	2	3	25	3000	6

Table No. 4: OUTPUT RESPONSE TABLE:-

Run order	Torque	Thrust	Local circularity error	Machining time
1	0.1	3.5	0.02	23.52
2	0.1	3.5	0.02	23.34
3	0.1	9	0.00	16.52
4	0.1	10	0.01	20.30
5	0.1	8	0.01	17.16
6	0.1	3.5	0.05	18.50
7	0.1	12	0.01	19.17
8	0.1	3.5	0.01	16.03
9	0.1	2.5	0.06	7.31

5.3.1 Normalization:

Here we use the smaller-the-better formula because of minimization of the above mentioned data. So, the used formula is

$$x_{ij} = \frac{(X_{ij})_{max} - X_{ij}}{(X_{ij})_{max} - (X_{ij})_{min}}$$

Table No. 5: GREY RALATIONAL GENERATION TABLE:-

Run order	Torque	Thrust	Local circularity error	Machining time
Ideal Sequence	1	1	1	1
1	0	0.8947	0.6667	1
2	0	0.8947	0.6667	0.3097
3	0	0.3158	1	0.1986
4	0	0.2105	0.8333	0.3923
5	0	0.4210	0.8337	0.2683
6	0	0.8947	0.1667	0.0111
7	0	0	0.8333	0.4621
8	0	0.8947	0.8333	0
9	0	1	0	0.4318

5.3.2 Calculation of Δ_{ij}

For this value we have to use $\Delta_{ij}=|x_{0j} - X_{ij}|$

Table No. 6: VALUE TABLE FOR Δ_{ij}:-

Run order	Torque	Thrust	Local circularity error	Machining time
Ideal Sequence	1	1	1	1
1	1	0.1053	0.3333	0
2	1	0.1053	0.3333	0.6903
3	1	0.6842	0	0.8014
4	1	0.7895	0.1667	0.6077
5	1	0.5790	0.1667	0.7317
6	1	0.1053	0.8333	0.9889
7	1	1	0.1667	0.5379
8	1	0.1053	0.1667	1
9	1	0	1	0.5682

5.3.3 Calculation of grey relational coefficient:

For obtaining the grey relational coefficient we have to use the given below formula

$$\gamma\,(x_{0j},X_{ij}) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{ij} + \xi\Delta_{max}}$$

Where ξ=Distinguishing coefficient varies from 0 to 1.Here we are taking ξ as 0.5.

Table No. 7: GREY RELATIONAL COEFFICIENT VALUE TABLE:-

Run order	Torque	Thrust	Local circular error	Machining Time
Ideal sequence	1	1	1	1
1	0.3333	0.8260	0.9375	1
2	0.3333	0.8260	0.9375	0.4201
3	0.3333	0.4222	1	0.3842
4	0.3333	0.3877	0.7500	0.4514
5	0.3333	0.4634	0.7500	0.4059
6	0.3333	0.8260	0.3750	0.3358
7	0.3333	0.3333	0.7500	0.4817
8	0.3333	0.8260	0.7500	0.3333
9	0.3333	1	0.3333	0.4681

5.3.4 Grey relational grades:

After determining the grey relational coefficient, we have to take average value of grey coefficients and this average value is called Grey Relational Grade.

$$\Gamma = \frac{1}{n} \sum_{k=1}^{n} \gamma(x_i(k), x_j(k))$$

Table No. 8: GREY RELATIONAL GRADE TABLE:-

Run order	Standard order	Grey Relational Grades
1	2	0.7742
2	1	0.6292
3	9	0.5349
4	3	0.4806
5	7	0.4881
6	5	0.4675
7	4	0.4746
8	8	0.5606
9	6	0.5337

Total Mean Grey relational grade = **0.5493**

Table No. 9: DESIGN OF EXPERIMENT OF GREY BASED RELATIONAL TAGUCHI METHOD:-

Feed rate	**Speed**	**Grades**	**S/N ratio**	**Mean**	**Fit means**	**Fits SN**	**Residual mean**	**Residual SN**
1	1	0.6292	4.02423	0.6292	0.609367	4.46470	0.019833	-0.44047
1	2	0.7742	**2.22294**	**0.7742**	0.679500	3.50695	0.094700	-1.28401
1	3	0.4806	6.36432	0.4806	0.595133	4.63984	-0.114533	1.72448
2	1	0.4746	6.47345	0.4746	0.473300	6.43816	0.001300	0.03529
2	2	0.4675	6.60437	0.4675	0.543433	5.48041	-0.075933	1.12396
2	3	0.5337	5.45406	0.5337	0.459067	6.61330	0.074633	-1.15925
3	1	0.4881	6.22982	0.4881	0.509233	5.82464	-0.021133	0.40519
3	2	0.5606	5.02694	0.5606	0.579367	4.86689	-0.018767	0.16005
3	3	0.5349	5.43455	0.5349	0.495000	5.99978	0.039900	-0.56524

5.3.5 Predict the optimum settings:

Prediction value of S/N ratio value can calculated from given formula

$$\text{Predicted S/N value } (\Gamma') = \Gamma_m + \sum_{i=1}^{\alpha} (\Gamma_i - \Gamma_m)$$

where Γ_m is the total mean of the grey relational grade, Γ_i the mean of the grey relational grade at the optimal level, and α is the number of the process parameter that significantly affect the multiple performance characteristics.

Table No. 10: PREDICTION VALUE TABLE:-

Factor levels for Prediction		Predicted S/N value	Predicted Mean value
Feed rate: 20	Speed: 2500	**3.50695**	**0.6795**

Table No. 11: S/N RATIO ANOVA TABLE:-

Source	Degree of freedom	Seq. SS	Adj. SS	Adj. MS	F	P
Feed rate	2	6.120	6.120	3.060	1.54	0.319
Speed	2	2.231	2.231	1.116	0.56	0.609
Residual Error	4	7.934	7.934	1.984		
Total	8	16.286				

Table No. 12: ANOVA TABLE FOR MEANS:-

Source	Degree of freedom	Seq. SS	Adj. SS	Adj. MS	F	p
Feed rate	2	0.02983	0.02983	0.014916	1.65	0.301
Speed	2	0.01224	0.01224	0.006120	0.68	0.559
Residual Error	4	0.03621	0.03621	0.009052		
Total	8	0.07828				

Table No. 13: RESPONSE TABLE TO S/N RATIO:-

For Smaller is better category

Level	Feed rate	Spindle speed
1	4.204	5.576
2	6.177	4.618
3	5.564	5.751
Delta	1.973	1.133
Rank	1	2

Table No. 14: RESPONSE TABLE FOR MEANS:-

Level	Feed rate	Spindle speed
1	0.6280	0.5306
2	0.4919	0.6008
3	0.5279	0.5164
Delta	0.1361	0.0844
Rank	1	2

5.3.6 Graphs:

Figure No. 5: Effective plot for mean

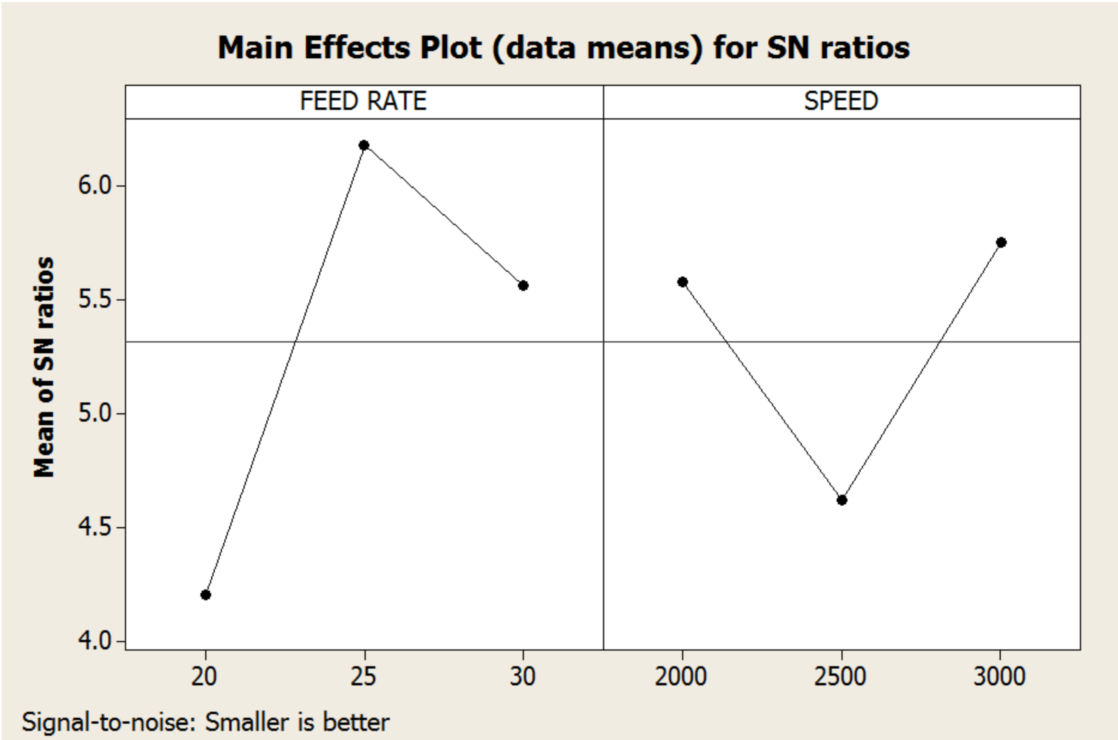

Figure No. 6: Effective plot for S/N ratio

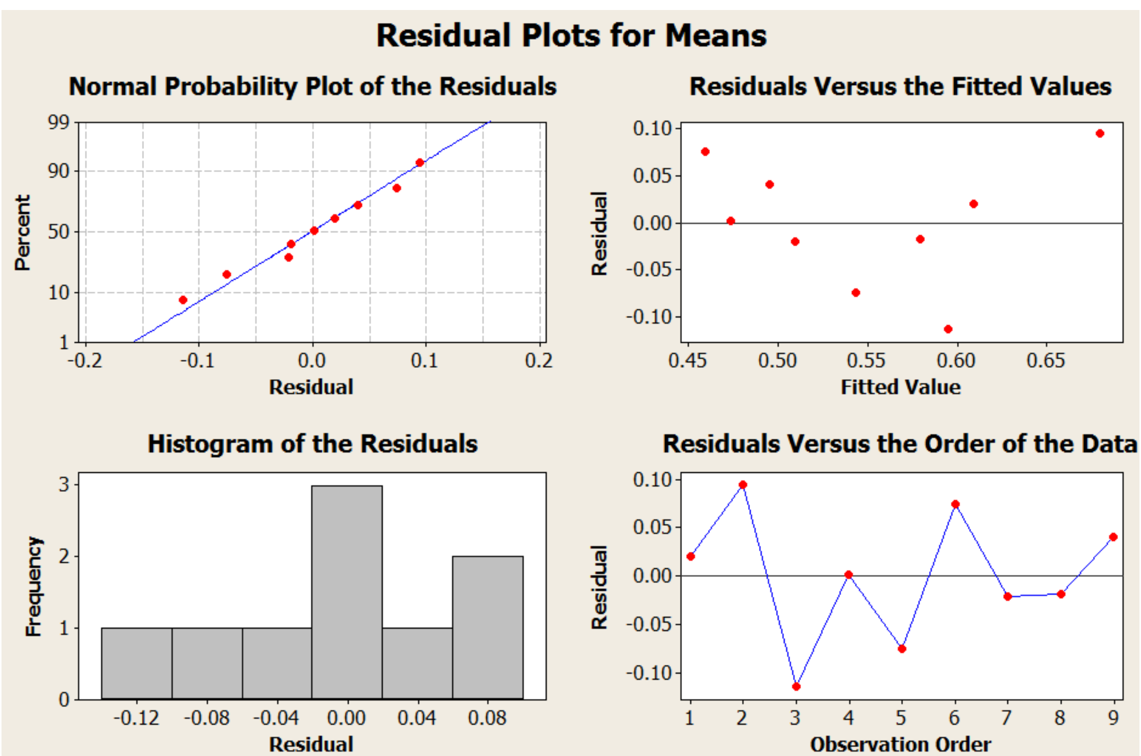

Figure No. 7: Residual Plot for Means

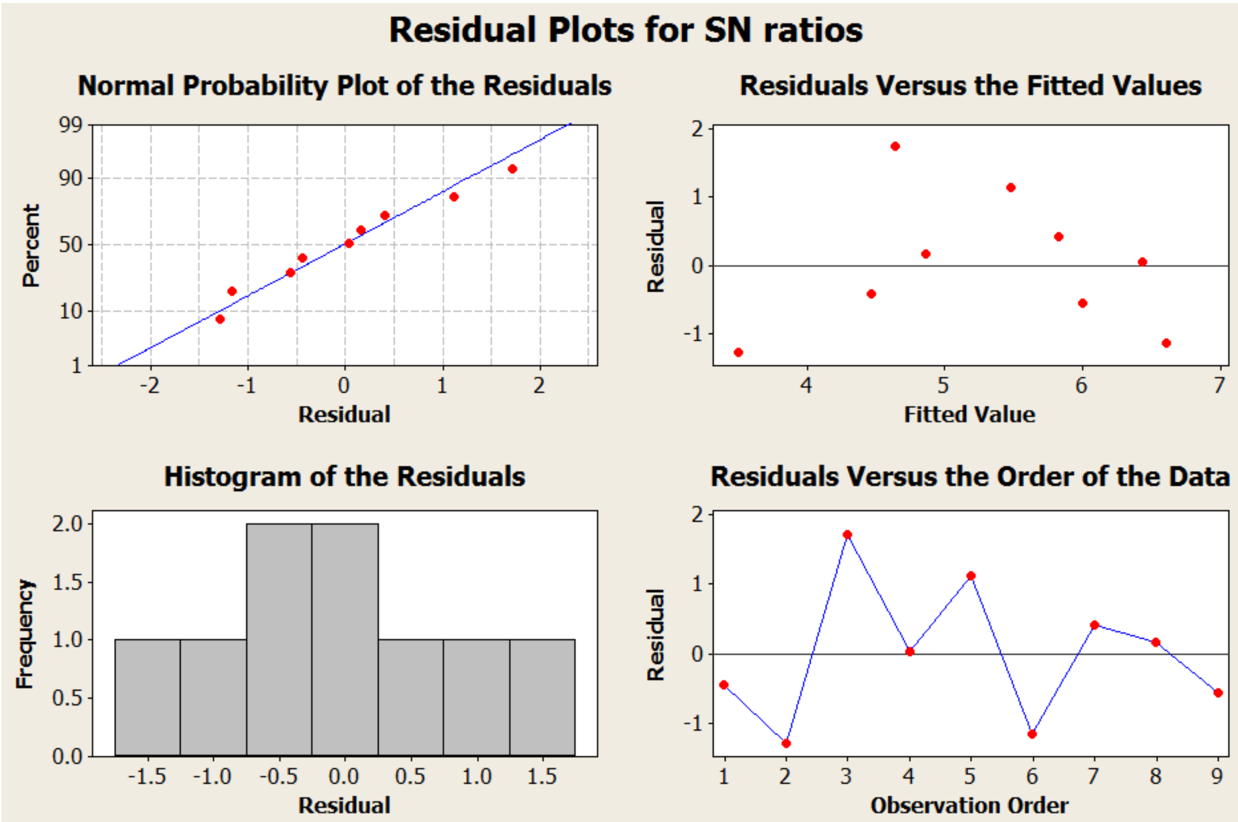

Figure No. 8: Residual Plot for S/N ratio

5.4 IMAGES FROM SCANNING ELECTRON MICROSCOPE:-

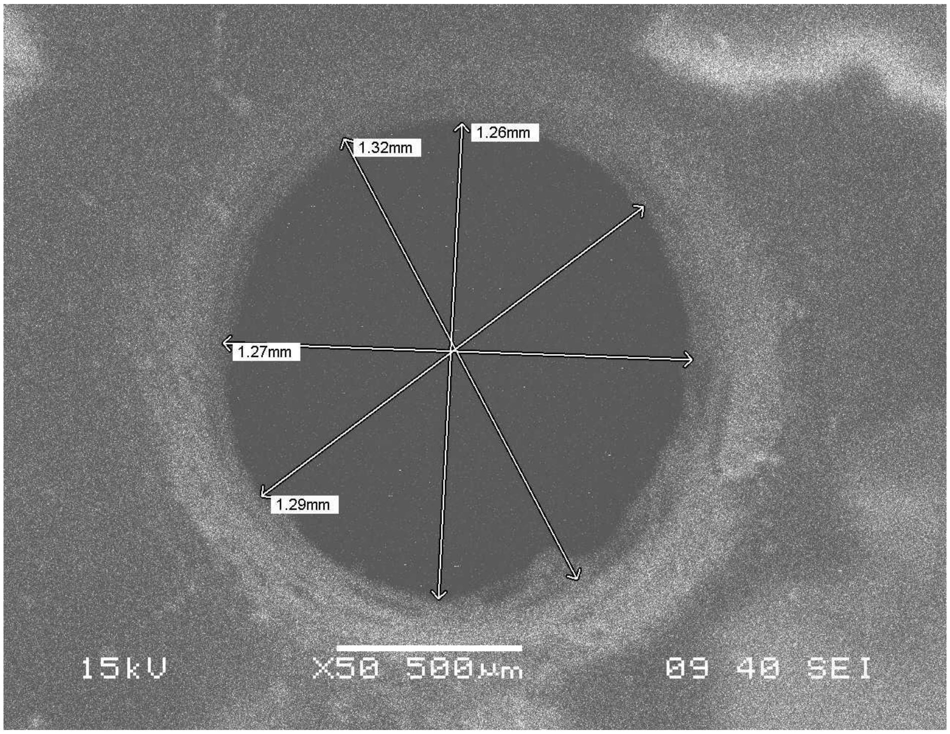

Figure No. 9: Micro hole at 25 mm/rev and speed 3000 rpm

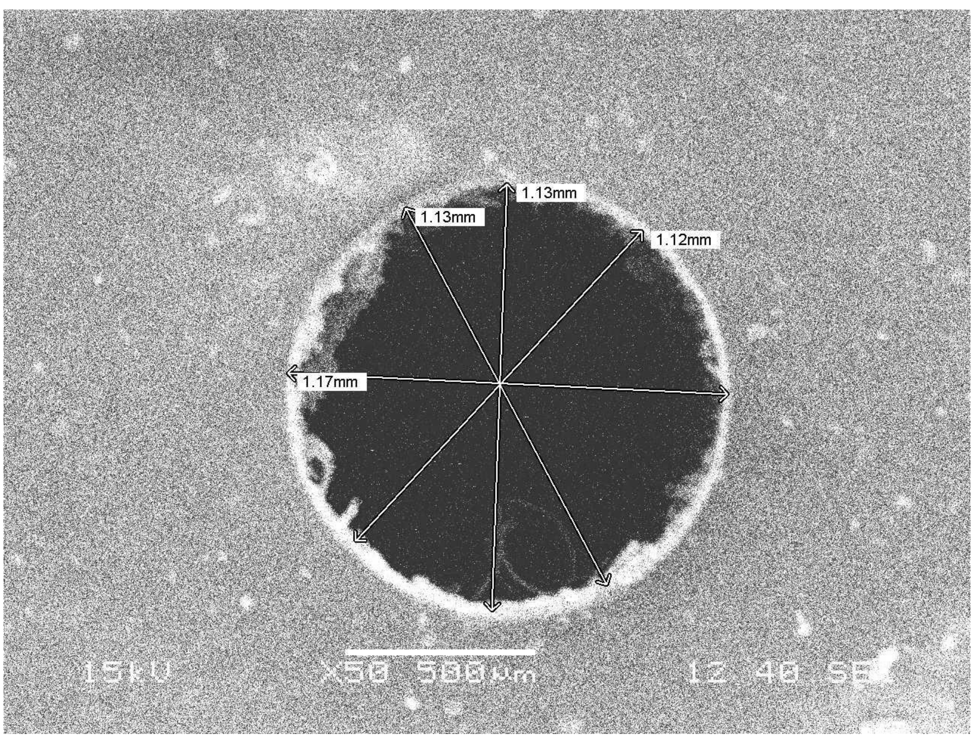

Figure No. 10: Micro hole at 25 mm/rev and 2500 rpm

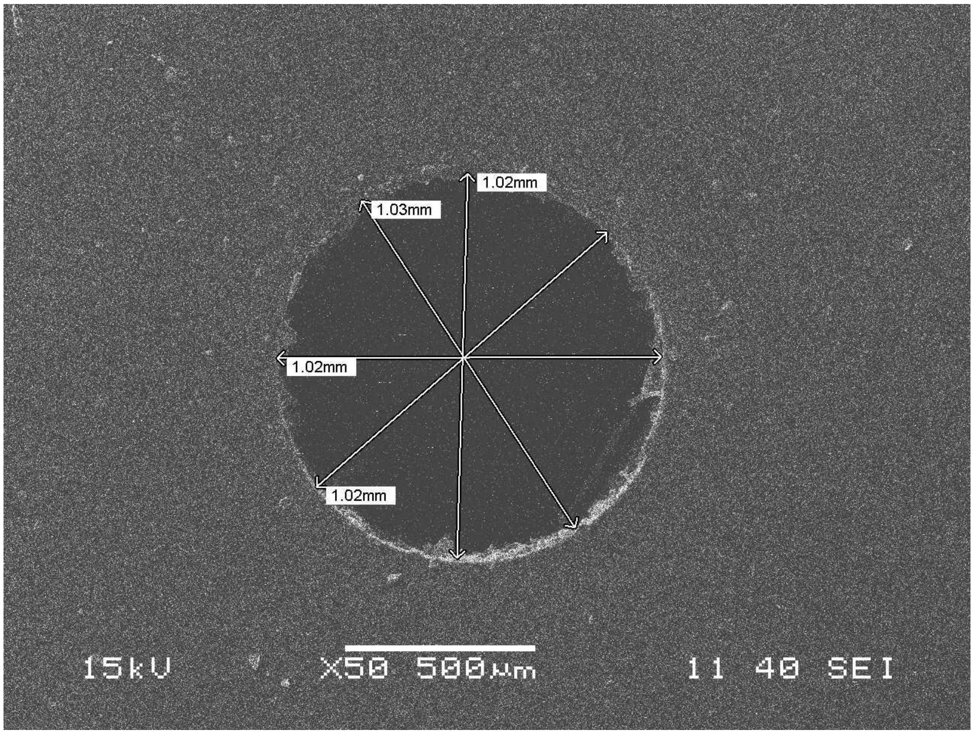

Figure No. 11: Micro hole at 20 mm/rev and 3000 rpm

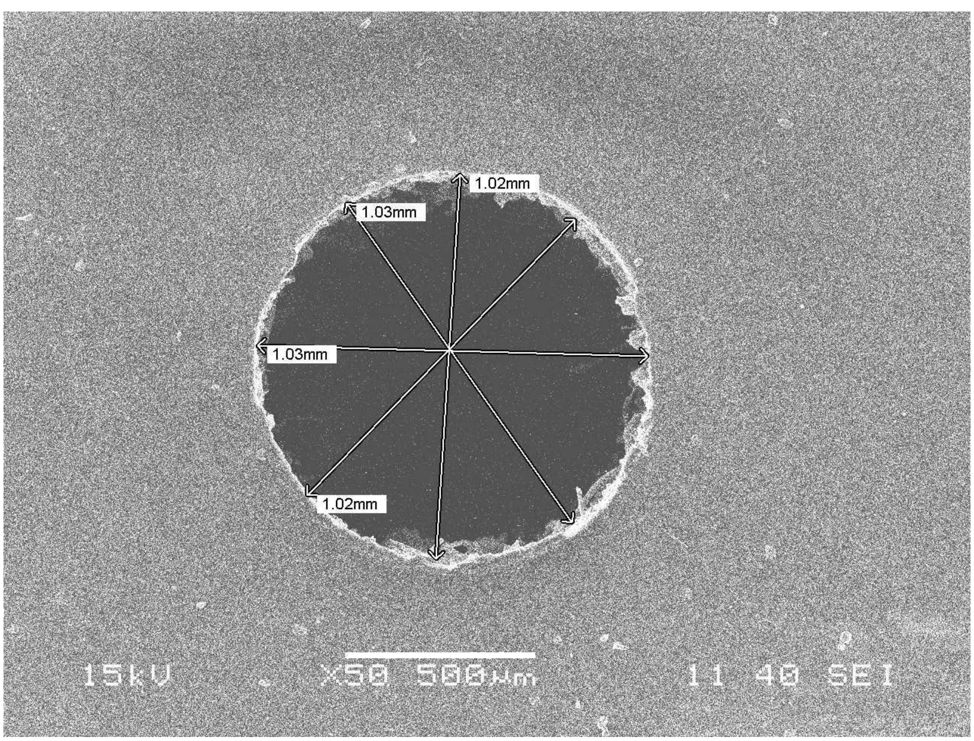

Figure No. 12: Micro hole at 30 mm/rev and 2000 rpm

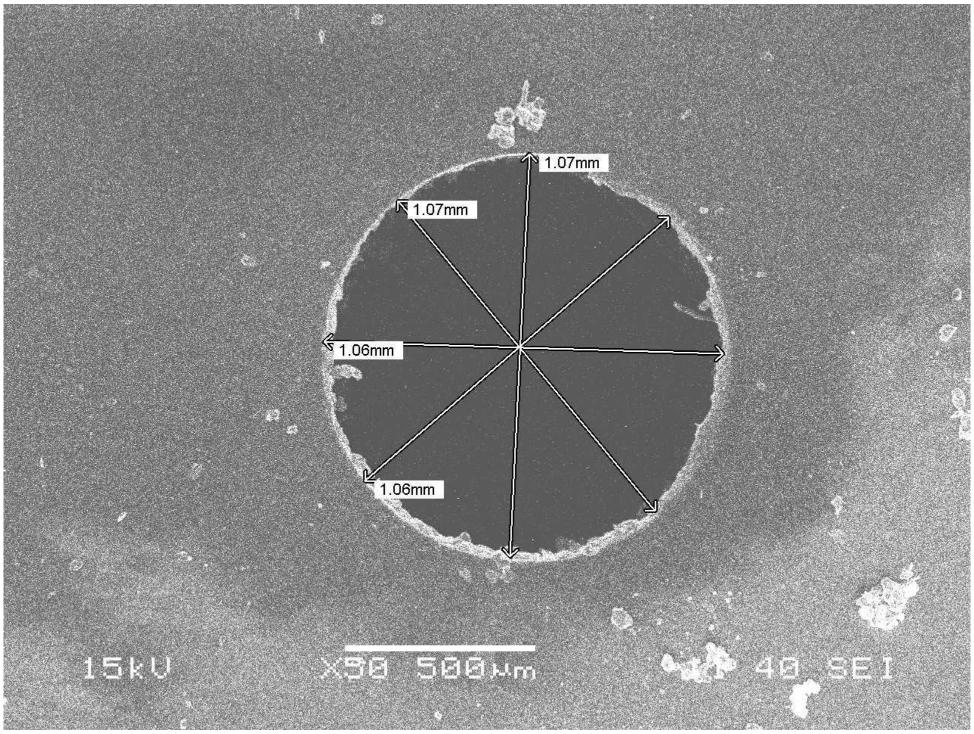

Figure No. 13: Micro hole at 25 mm/rev and 2000 rpm

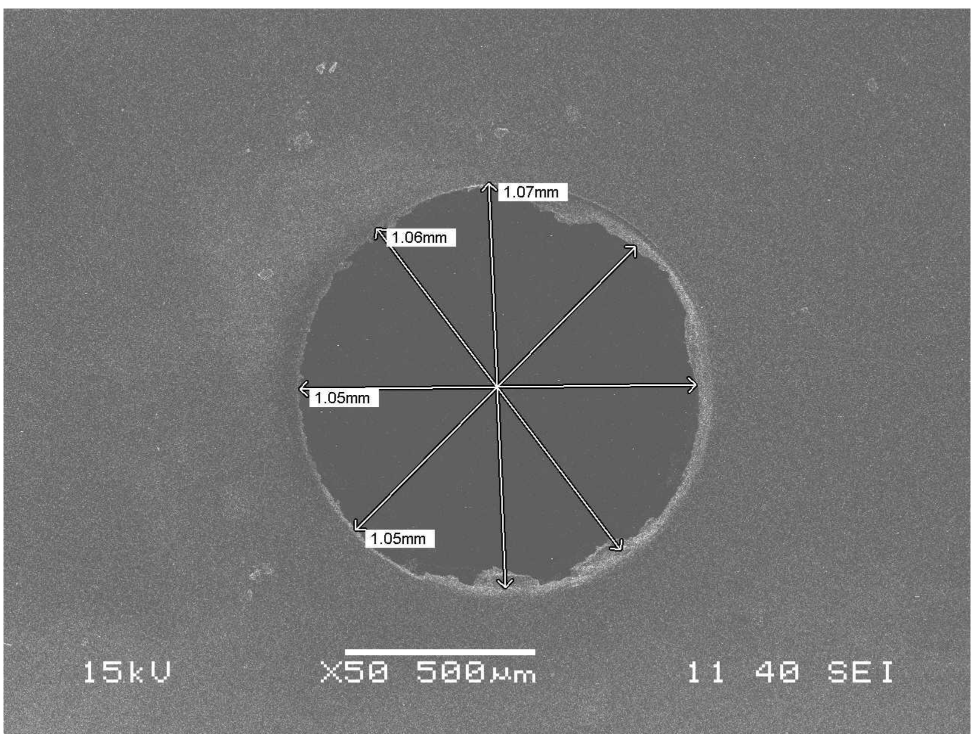

Figure No. 14: Micro hole at 20 mm/rev and 2000 rpm

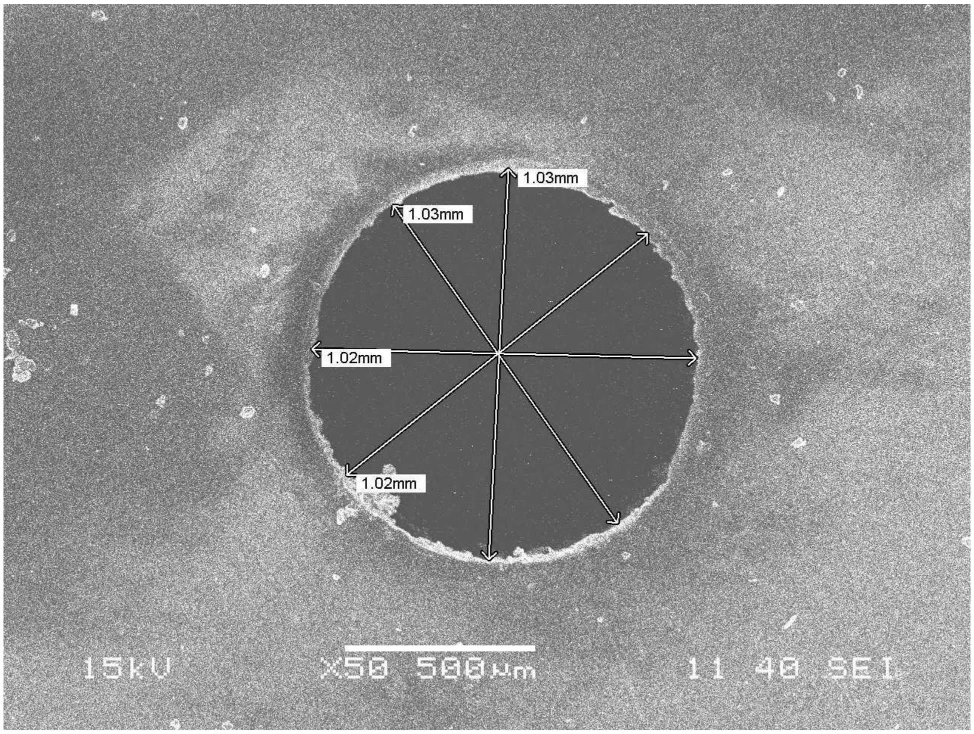

Figure No. 15: Micro hole at 30 mm/rev and 2500 rpm

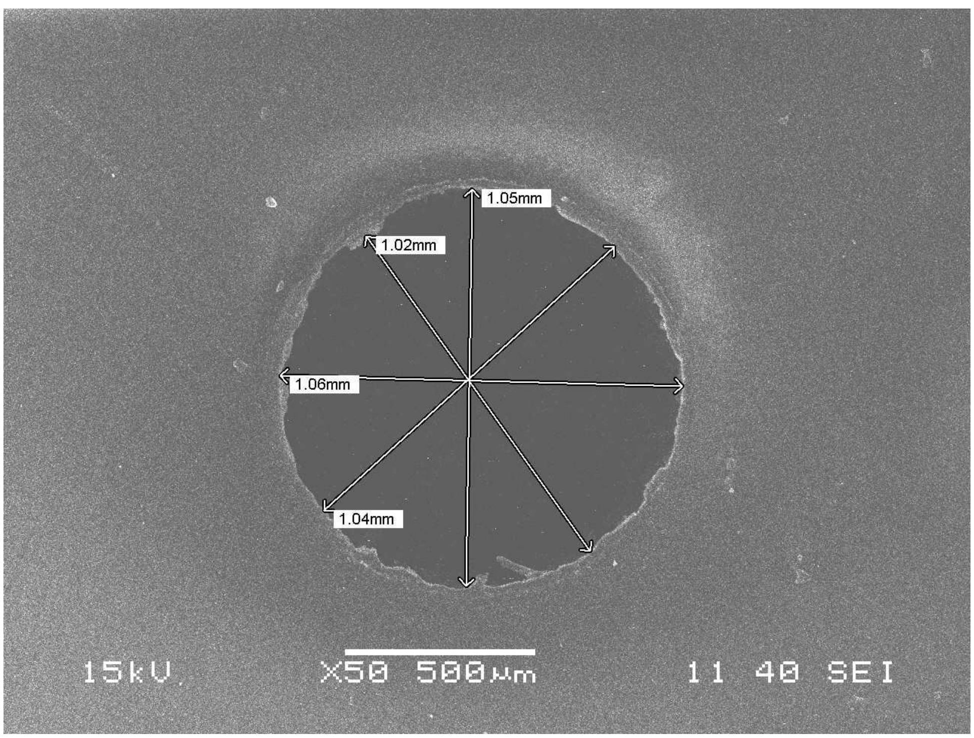

Figure No. 16: Micro hole at 20 mm/rev and 2500 rpm

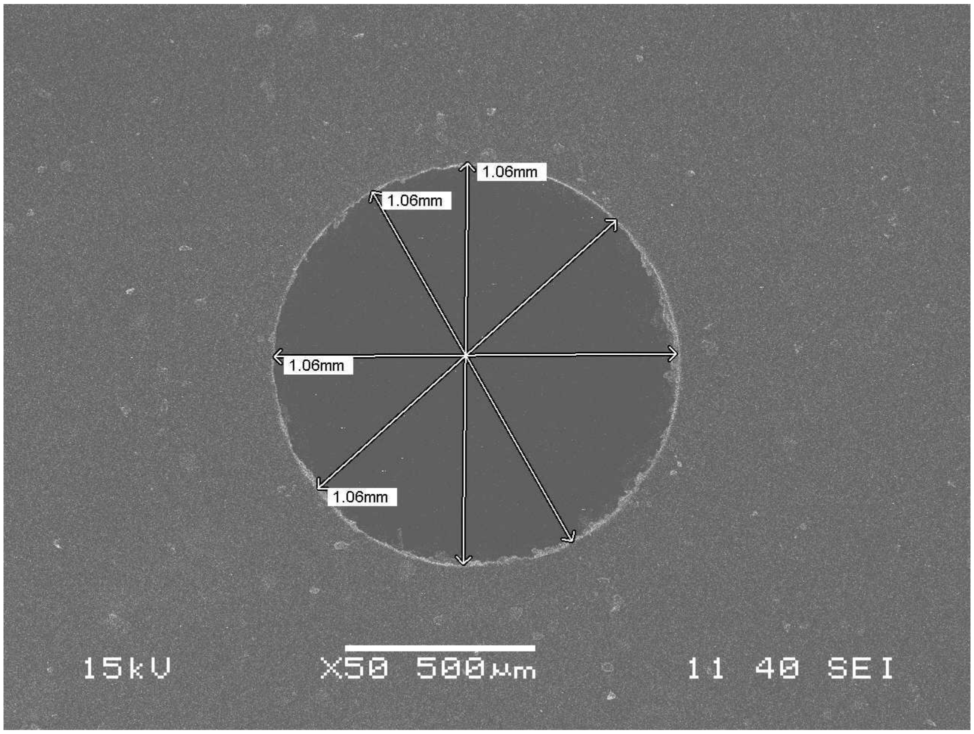

Figure No. 17: Micro hole at 30 mm/rev and 3000 rpm

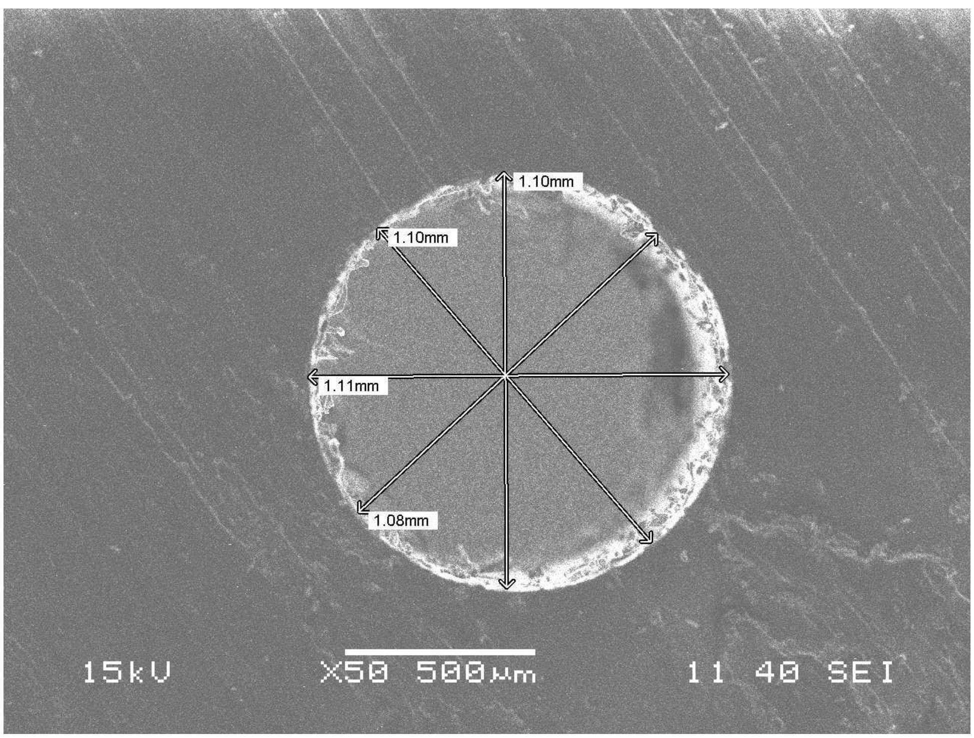

Figure No. 18: Micro hole at 18 mm/rev and 2100 rpm

CHAPTER-6 RESULTS AND DISCUSSIONS:

The following results concluded from this experiment such that our main objective to optimize the modeling of process parameters of micro-drilling in PMMA material. Such as

1. Here the optimal conditions of two process parameters are 20mm/min of feed rate and 2500 RPM of spindle speed.
2. From the graph of smaller-the-best of S/N ratio the minimum value occurred at **2.22294** for feed rate in 1^{st} level and for spindle speed in 2^{nd} level.
3. From the graph of residual versus fitted value the points are not form any standard platform. Hence it shows no error.
4. From the normal probability plot of residuals 5 points are closely placed at the slop of standardized residual versus percent.
5. In the normal probability plot of the residuals for mean and S/N ratio, All the points lie close to the line, Hence the experiment is correct and also visible in the interval of [-2,2].
6. In the ANOVA table for means the P-value has minimum value i.e. 0.301 in feed rate parameter. Hence feed rate is more significant than spindle speed.
7. The increased improvement value of S/N ratio is 1.28401 by 57.76% at optimal condition and for reduced improvement value of mean is 0.0947 by 12.23%.
8. Ranking order of the experiment is $\Gamma_{03}>\Gamma_{05}>\Gamma_{07}>\Gamma_{08}>\Gamma_{04}>\Gamma_{01}>\Gamma_{09}>\Gamma_{06}>\Gamma_{02}$.
9. As a result of this experiment the multi-characteristics of the micro-drilling process with 1mm solid carbide drill bit is successfully optimized.
10. Feed rate parameter has the significant characteristics in this experiment as the rank in responsible table is 1.
11. The histogram plot represents normally distributed graph. Hence our experimental analysis is correct.

<u>CHAPTER-7 CONCLUSION</u>:

Experiments are planned and conducted on radial CNC drilling machine with solid carbide drill-bit and PMMA sheet taken as work-piece material to optimize the micro-drilling operation. The purposed Grey based relational Taguchi method is beneficial for optimization of multi-responded control parameters in micro-drilling process. The main objective of this study was to determine the optimum settings of feed rate and spindle speed so that the thrust force, torque, local circularity error, and machining time can be minimized. The summarized conclusions are given as

1) As the feed rate increases all above mentioned output parameters of micro-drilling decrease. Hence, it is concluded that for lowering torque, thrust, machining time and circularity error we have to give higher value of feed rate for better smoothing in cylindrical hole.
2) In case of spindle speed, output parameters of micro-drilling increase with increasing value of speed.
3) The optimum settings for this experiment are at 20mm/min (level-1) of feed rate and 2500 RPM (level-2) of spindle speed.
4) It is found that feed rate influences 38.1067% more, followed by 16.8131% of spindle speed in this experiment.
5) Confirmatory test was held at 18 mm/rev of feed rate and 2100 rpm of spindle speed, and this also satisfies the real requirements of the determined optimum settings in micro-drilling operation of aerospace material.

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22) http://www.scribd.com/doc/52174150/00-Introduction-to-Machining

Appendix:

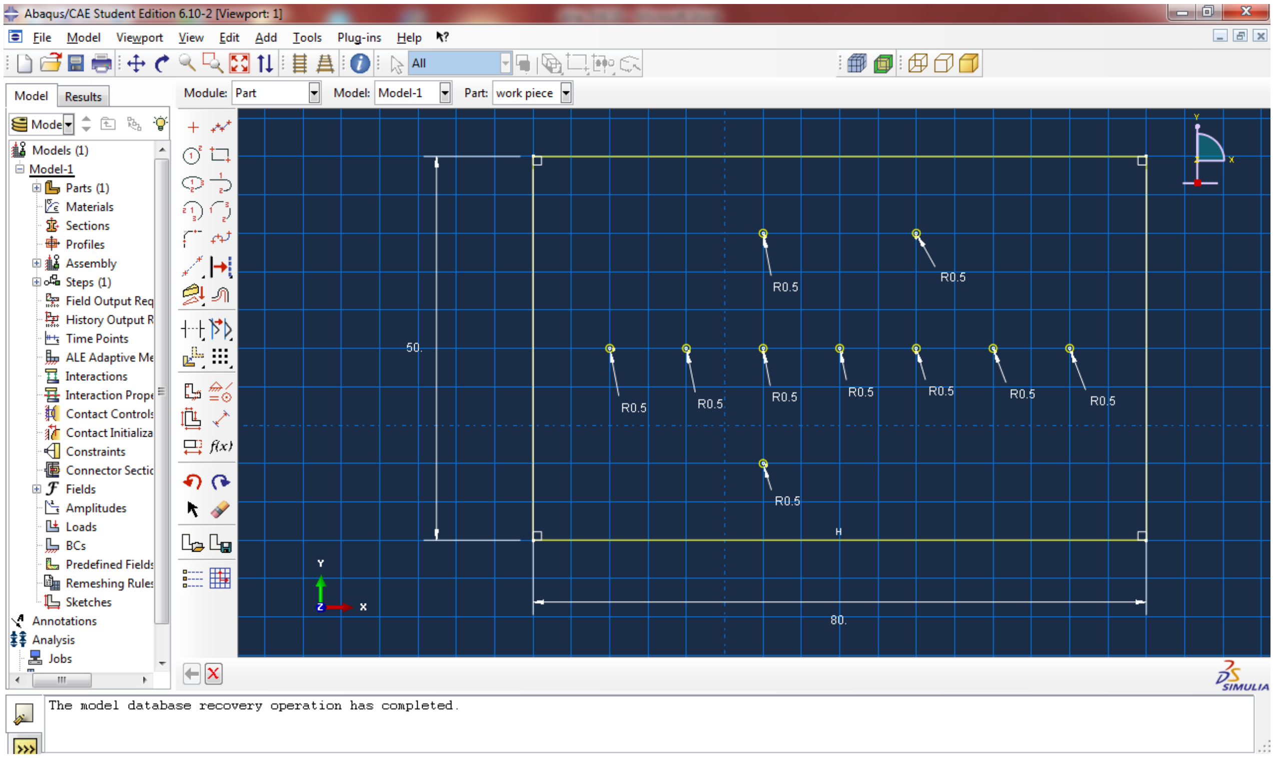

Figure No. 19: 1mm micro holes in abacus software.

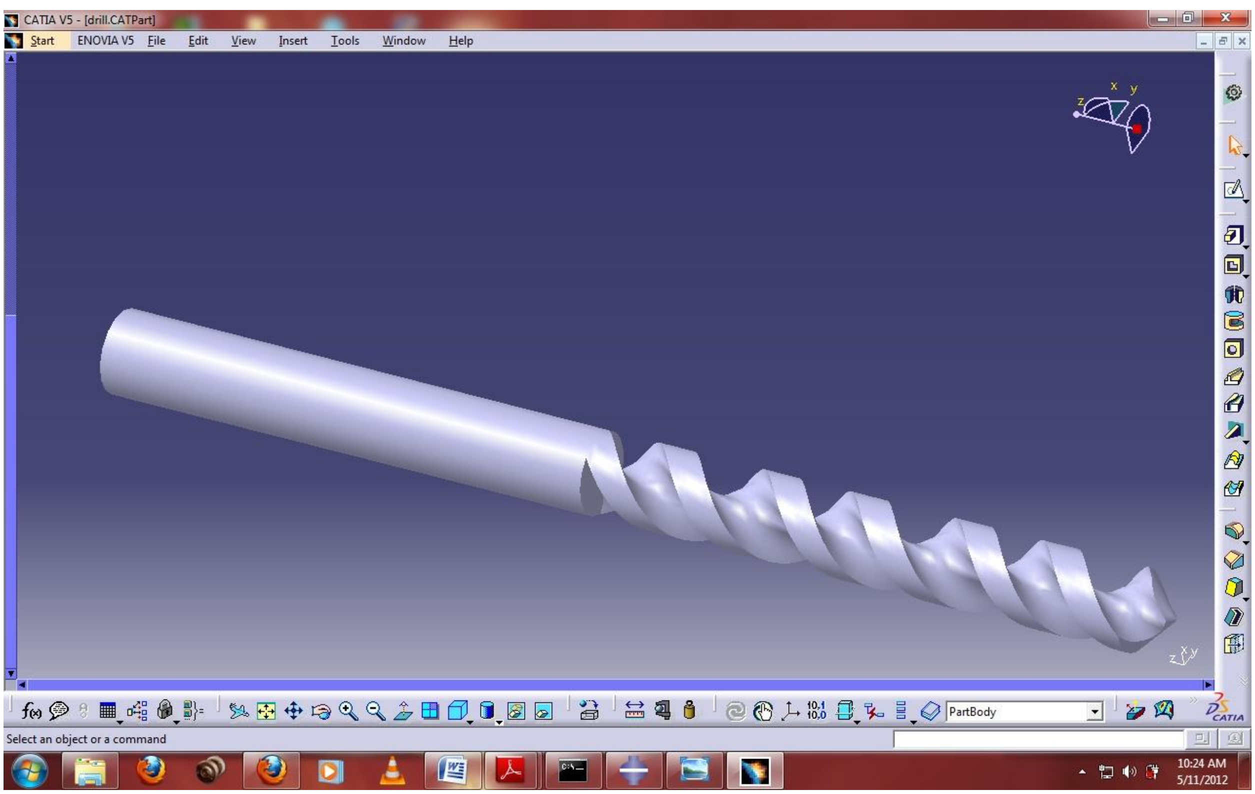

Figure No. 20: Drill bit of 1mm structure in CATIA software.